Response to comment by Cuk *et al.*

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Abstract

In a recent study of the optical conductivity of the Bi-2212 high temperature superconductor, Hwang, *et al.* have confirmed the mass-renormalization changes observed in ARPES but find that such changes are no longer observed in the highly overdoped regime. In a comment on this study, Cuk, *et al.* challenge this conclusion and present ARPES evidence for a kink in the superconducting state in the highly overdoped regime. We show, however that two doping dependent properties in the data of Cuk *et al.*, the frequencies of the superconducting gap and the Van Hove singularity, suggest a T_c that is higher than the 58 K quoted, and that their sample is not as highly overdoped as claimed. As a result, these data can not refute the claim of Hwang *et al.* that the kink is absent in the highly overdoped region.

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Since its initial observation[1], there has been continued debate as to the origin and temperature dependence of a mass-renormalization evident in the cuprates. A change in the magnitude of the renormalization on entering the superconducting state, has emerged as a phenomenon that could help in identifying any coupling mechanism[2,3,4]. In a recent optical conductivity study, Hwang, *et al.*[5] have confirmed the mass-renormalization changes observed in ARPES[4]. Importantly, these authors highlight the fact that such changes are no longer observed in the highly overdoped regime. In a comment on the latter study, Cuk, *et al.*[6] suggest that this conclusion is unfounded and present ARPES evidence for the presence of a kink developing in the superconducting state in the highly overdoped regime. Here we examine the latter claim in detail.

Cuk, *et al.*[6] show ARPES data recorded in the (π, 0) region from an overdoped sample (T_c = 58 K). Such data shows two characteristic doping dependent properties well documented in the literature, a gap in the superconducting state that gets smaller with increased doping and the bonding state Van Hove Singularity (VHS), corresponding to the binding energy at the (π,0) point. With increased doping, the VHS shifts to lower binding energy. In Fig. 1 we show the measured superconducting gap (circles) at the Fermi surface in the vicinity of the (π,0) region. The data are taken from our own studies[7] and the group of Shen[8]. We also show the gap measured in the cited study of Gromko *et al.*[9]. The Gromko data would appear to have a larger gap than one would anticipate for a sample with T_c = 58 K. In particular, the gap for their "58 K" sample is larger than the gap reported by the Shen group[8] for an overdoped sample with T_c = 65 K. The discrepancy becomes even more striking if one examines the energy of the VHS. In Fig. 1 we show (triangles) a compilation of different measurements of the VHS[8,9,10]. The studies all show the same reduction in binding energy with increasing doping. The data of Gromko *et al.*[9] cited in the accompanying comment is again inconsistent with this trend. Indeed, both the measured superconducting gap and the VHS would indicate a T_c higher than the quoted 58K, and probably higher than the first neighboring point with T_c of 65 K measured by Feng *et al.*[8]. A shift in doping level due to the loss of oxygen is common for overdoped samples and such an effect will certainly be present at the doping level of Gromko *et al.*'s[9] sample. We are left with the conclusion that the comment of Cuk *et al.*[6] does not provide any experimental evidence that refutes the claims in the paper of Hwang *et al.*[5].

Finally we make the observation that the change in the mass renormalization that accom-

panies the superconducting transition weakens beyond the detection limits in the overdoped regime for doping levels in excess of approximately 0.23 - 0.24 in both optical conductivity and photoemission. In fact a similar conclusion has been made in the recent photoemission study of Kim *et al.*[10] from the (π,0) region.

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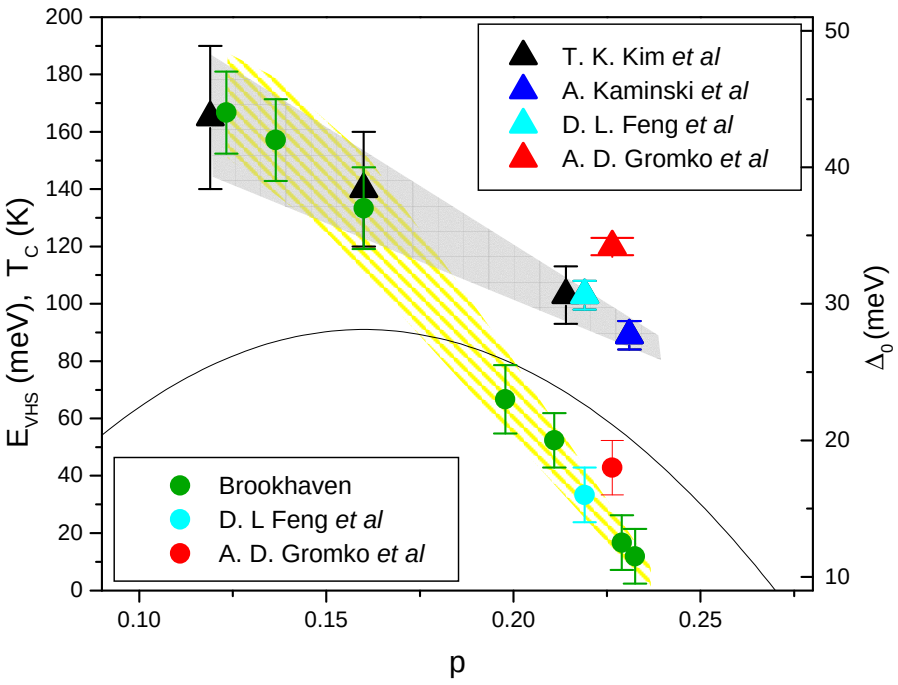

FIG. 1: The superconducting gap, Δ_0, measured at (π,k_F) (circles) and the energy of the bonding state, E_{VHS}, measured at (π,0) (triangles) as a function of doping for Bi2212. Green points have been measured at Brookhaven, cyan are from Feng *et al.*[8], black triangles are from Kim *et al.*[10] and blue triangle is from Kaminski *et al.*.[2] Red data points are from Gromko[9].